Jet Propulsion Laboratory
California Institute of Technology

The Deep Space Positioning System (DPS) – Navigator Concept for the Lunar Gateway

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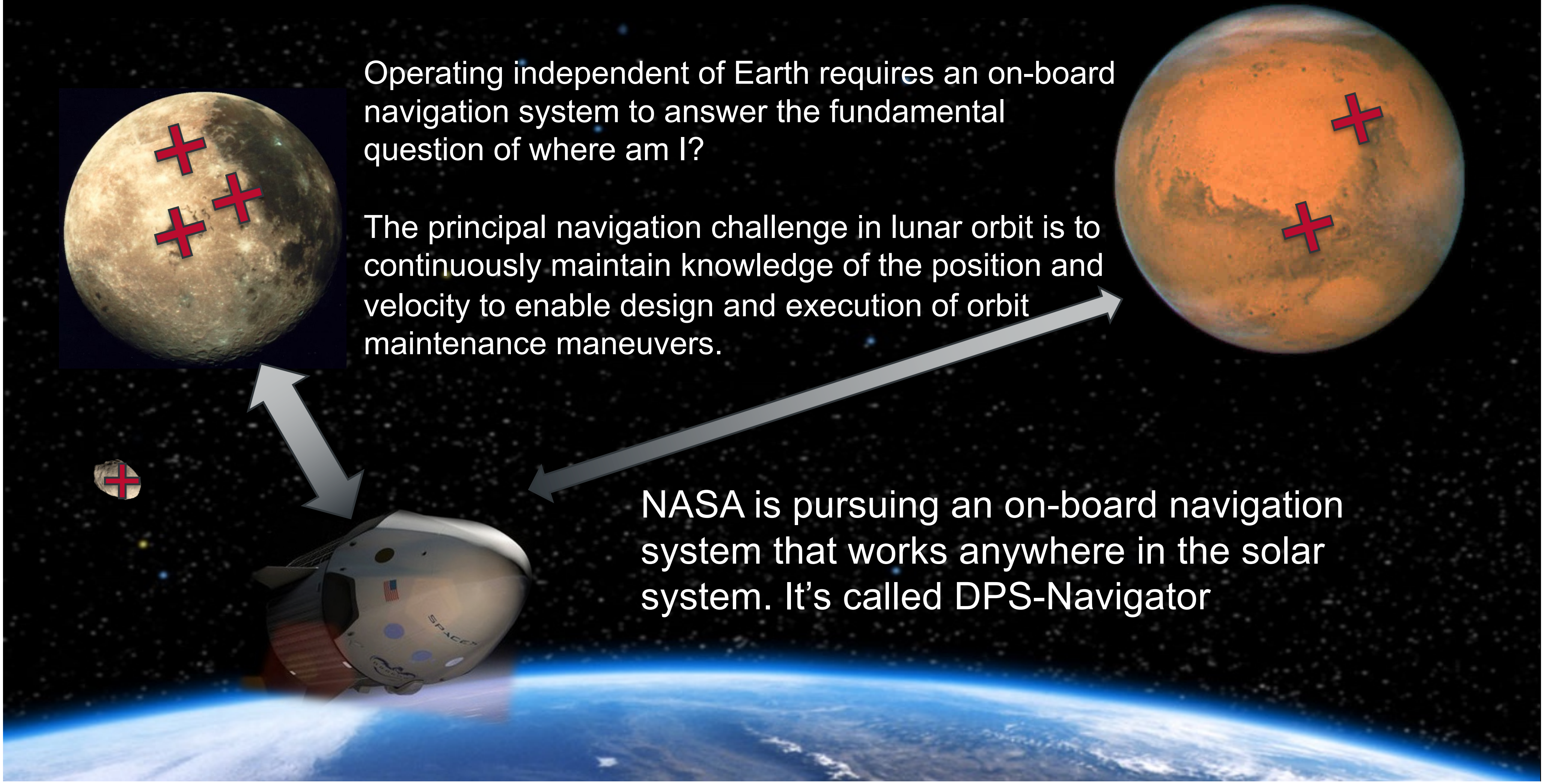
2019 AAS Guidance and Control Conference, Breckenridge, Colorado
Session: Autonomous Navigation in the Earth-Moon System

February 4, 2019

Deep Space Navigation Challenges



Operating independent of Earth requires an on-board navigation system to answer the fundamental question of where am I?

The principal navigation challenge in lunar orbit is to continuously maintain knowledge of the position and velocity to enable design and execution of orbit maintenance maneuvers.

NASA is pursuing an on-board navigation system that works anywhere in the solar system. It's called DPS-Navigator

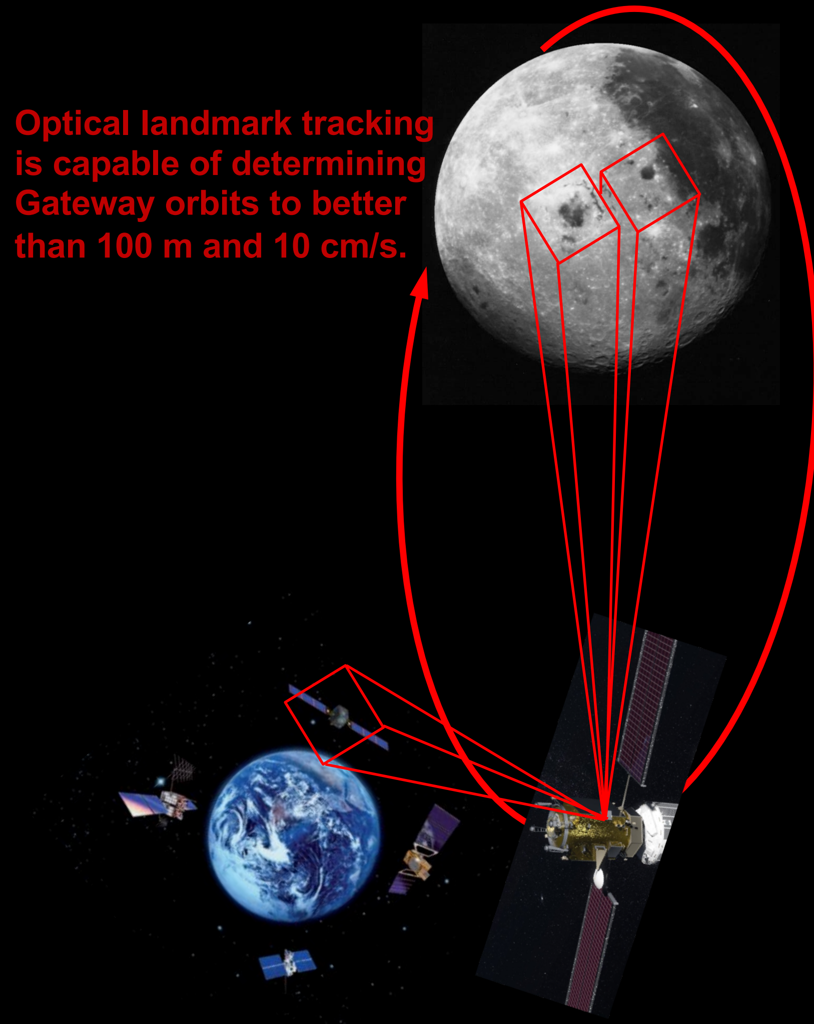
What is the Deep Space Positioning System (DPS) - Navigator

A self-contained autonomous navigation hardware and software system that provides spacecraft on-board navigation throughout the solar system.

How Does DPS-Navigator Work?

In the Earth-Moon vicinity, DPS-Navigator optically observes communications or GPS satellites. Closer to the Moon, lunar landmarks serve as optical beacons.

On-board position/velocity are determined and orbital maneuvers computed to maintain the spacecraft orbit.



The Implementation Problem

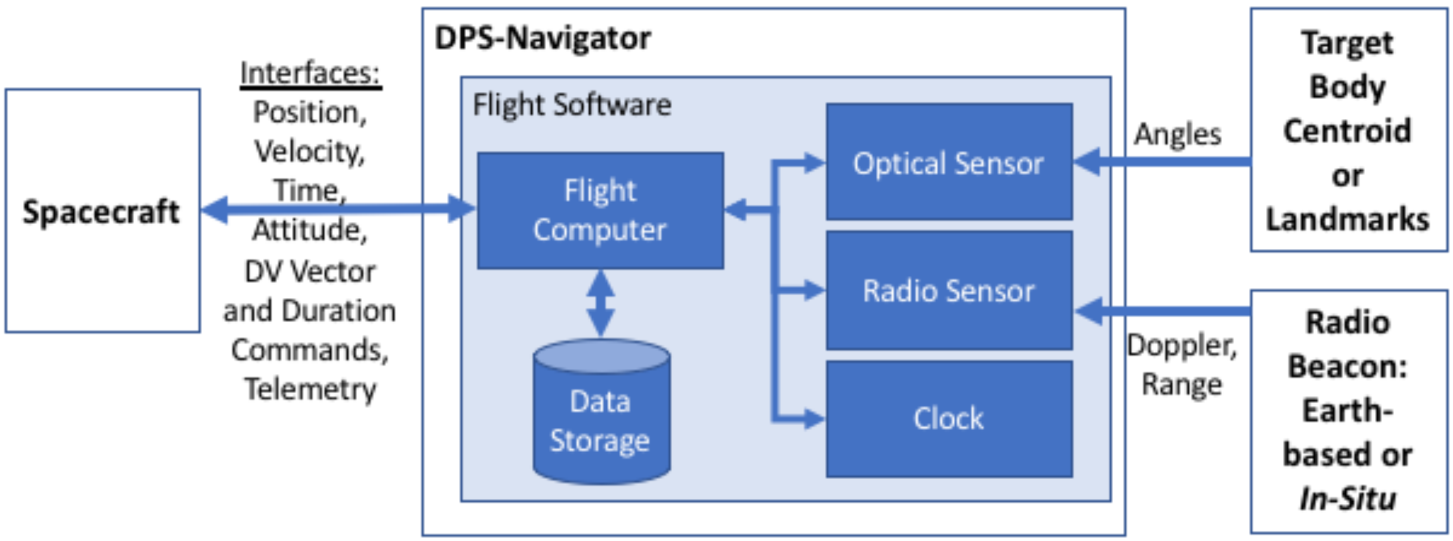
Moving beyond point-solutions for every mission

- AutoNav has flown three times (Deep Space 1, Stardust, Deep Impact)
- Each flight was a custom application requiring full test and validation activities
- Each flight had moderate to severe software integration “issues”
- Substantial cost and risk was incurred by a unique flight-by-flight instantiation

The DPS-Navigator Solution:

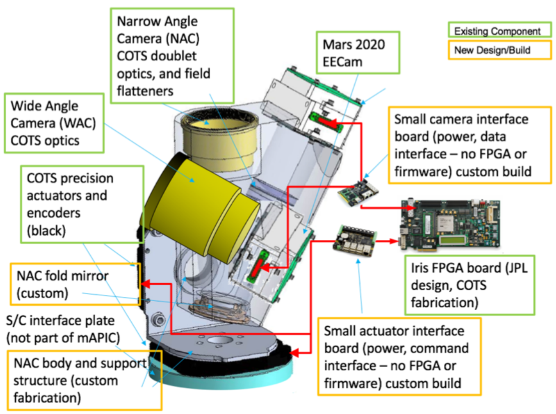
Self-contained like a star tracker or GNSS receiver:

- Small (25 x 12 x 12 cm)
- Light-weight (< 5 kg)
- Low power (<12 W)
- Low data requirements (< 50 MB per day)
- Common interfaces to reduce/eliminate recurring test and verification activities



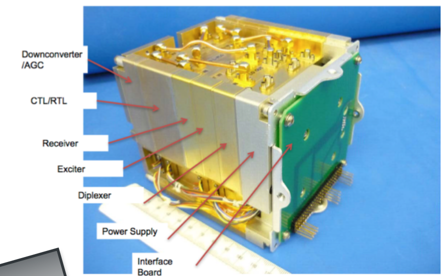
Flight-Proven/Inheritance Technologies

Camera, radio, clock, steering actuators and flight software



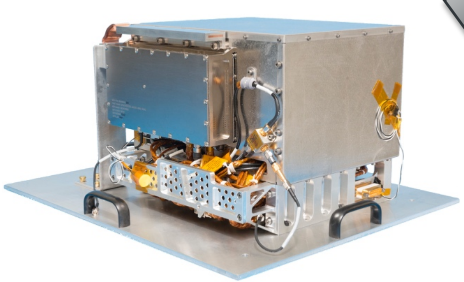
Mini-APIC OpNav Camera

Integrated DPS-Navigator Instrument



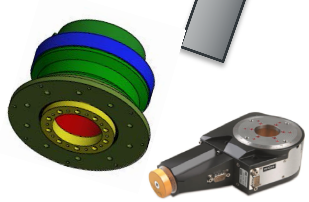
Iris Software Defined Radio

Extracts one-way radio observables and hosts AutoNav FSW

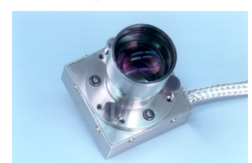


STMD Deep Space Atomic Clock

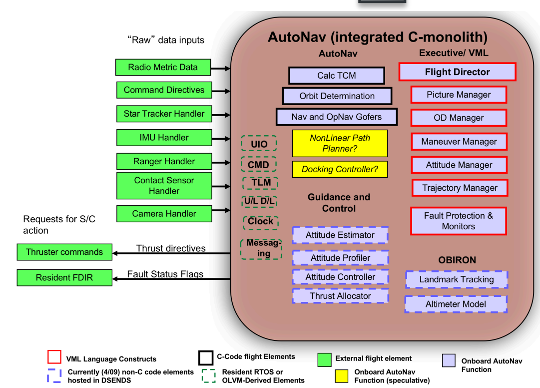
“DSN-Quality” frequency and time reference for one-way radio



OCO-3 Actuators



ASC Star-tracker

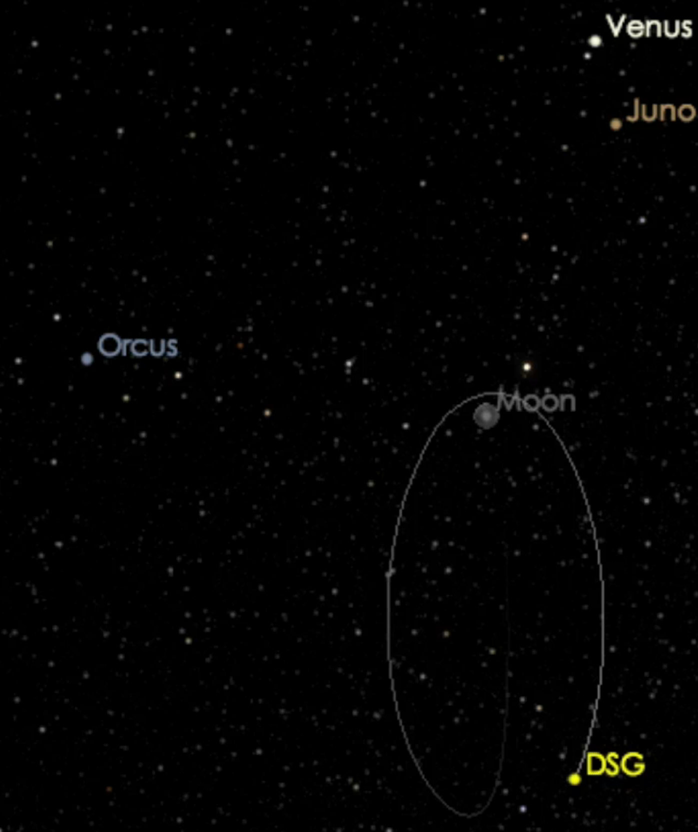


Deep Impact AutoNav
Flight Software

Application to Lunar Gateway

How much DSN radiometric or on-board optical tracking is required for operations in the lunar Gateway NRHO?

Near Rectilinear Halo Orbit (NRHO)



Orbit period: 6.5 days

Perilune radius: 3200 km

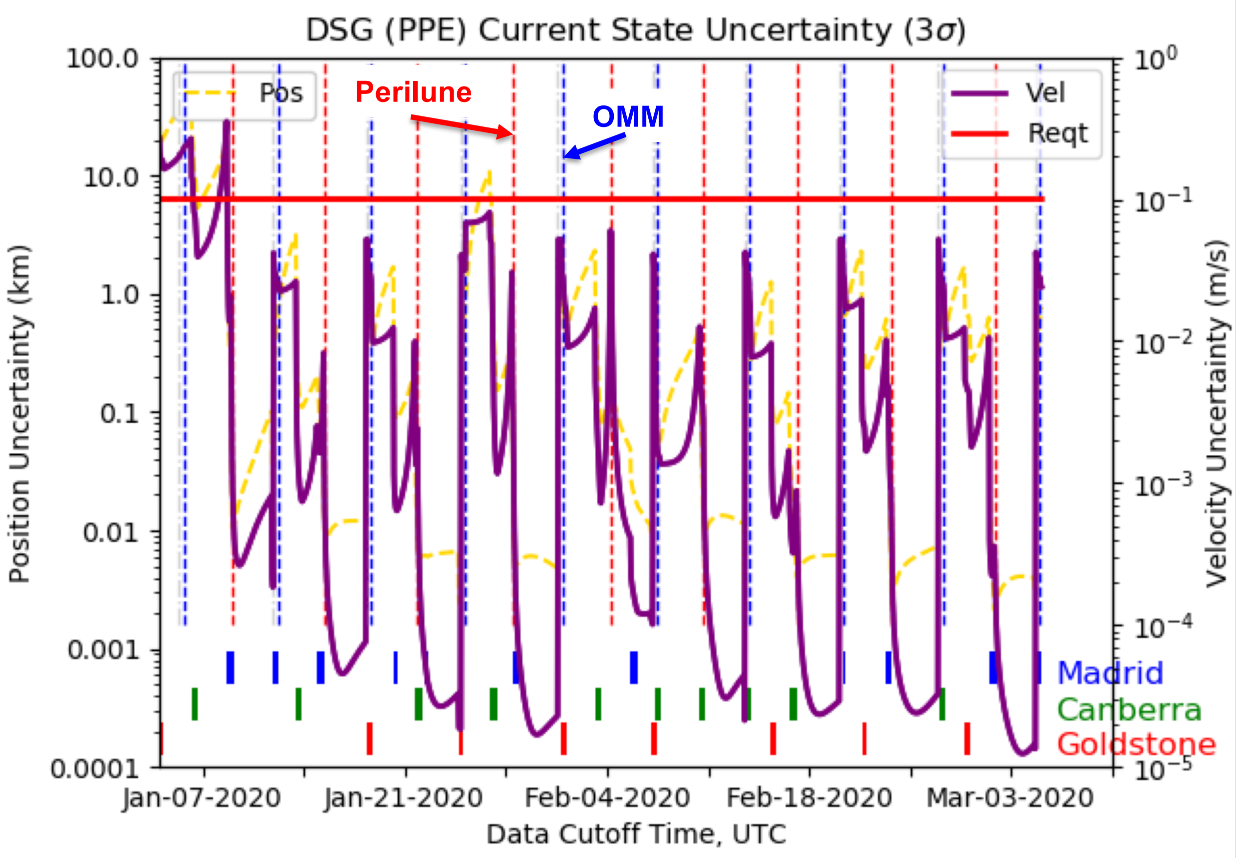
Apolune radius: 70,000 km

Nearly stable with inexpensive orbit maintenance costs

Inexpensive transfers from/to Earth and other Lunar orbits

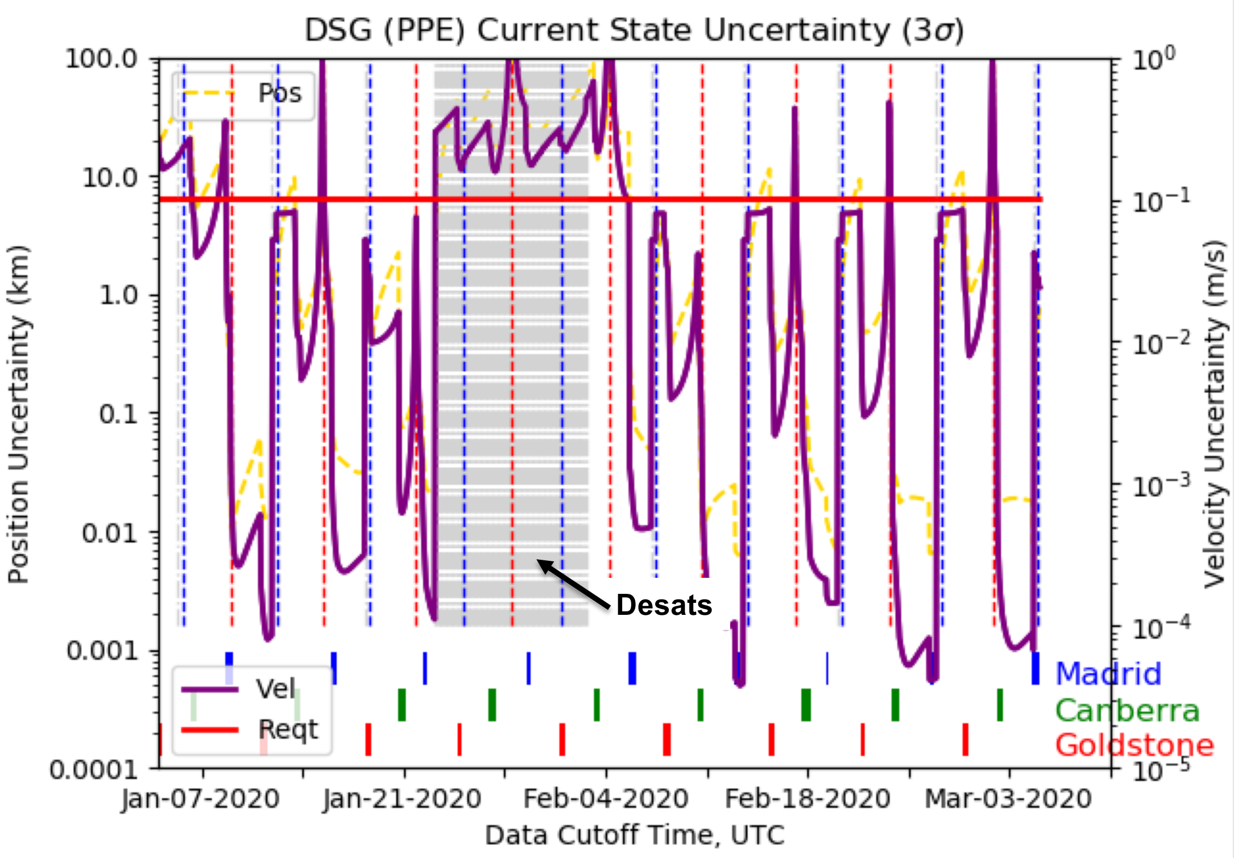
Orbit Determination Results: No Crew

DSN Tracking Only: 3 Passes/Week



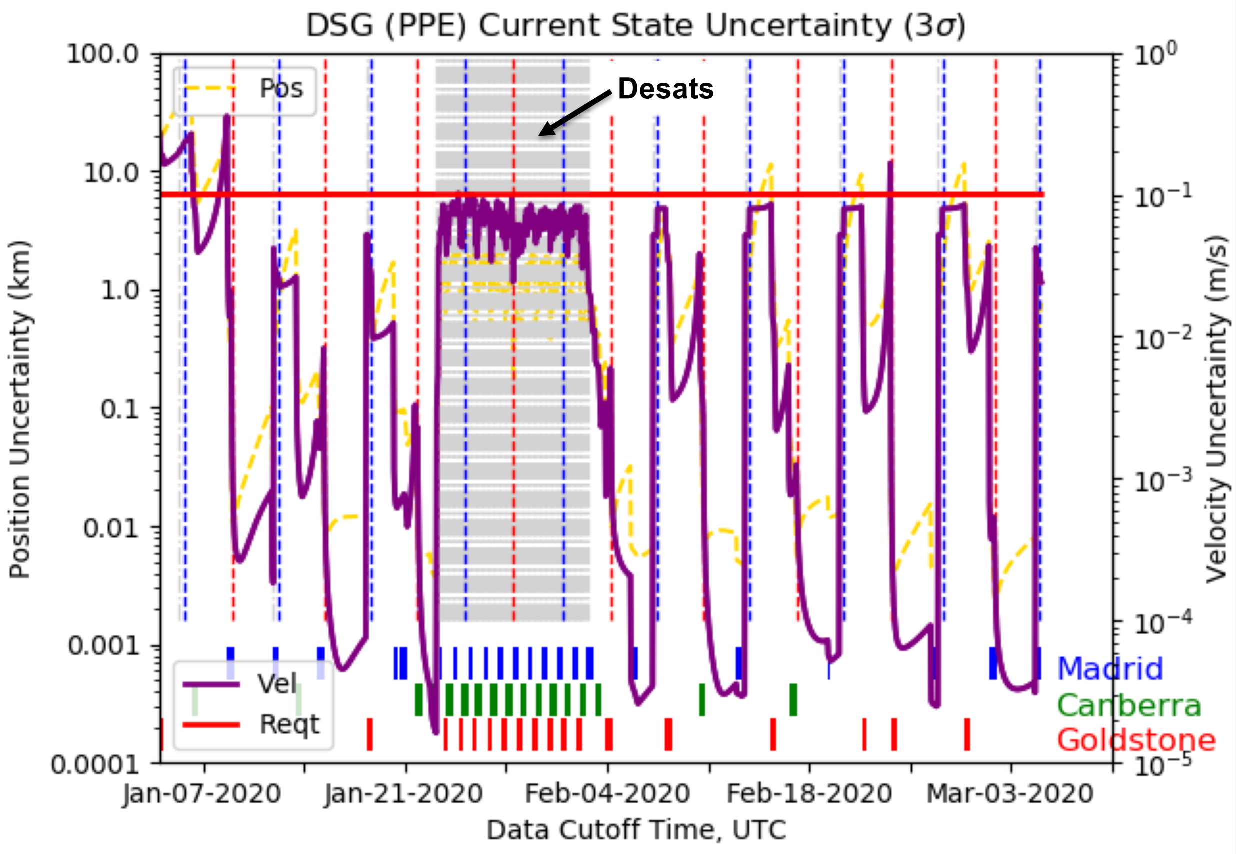
Orbit Determination Results: With Crew

DSN Tracking Only: 3 Passes/Week

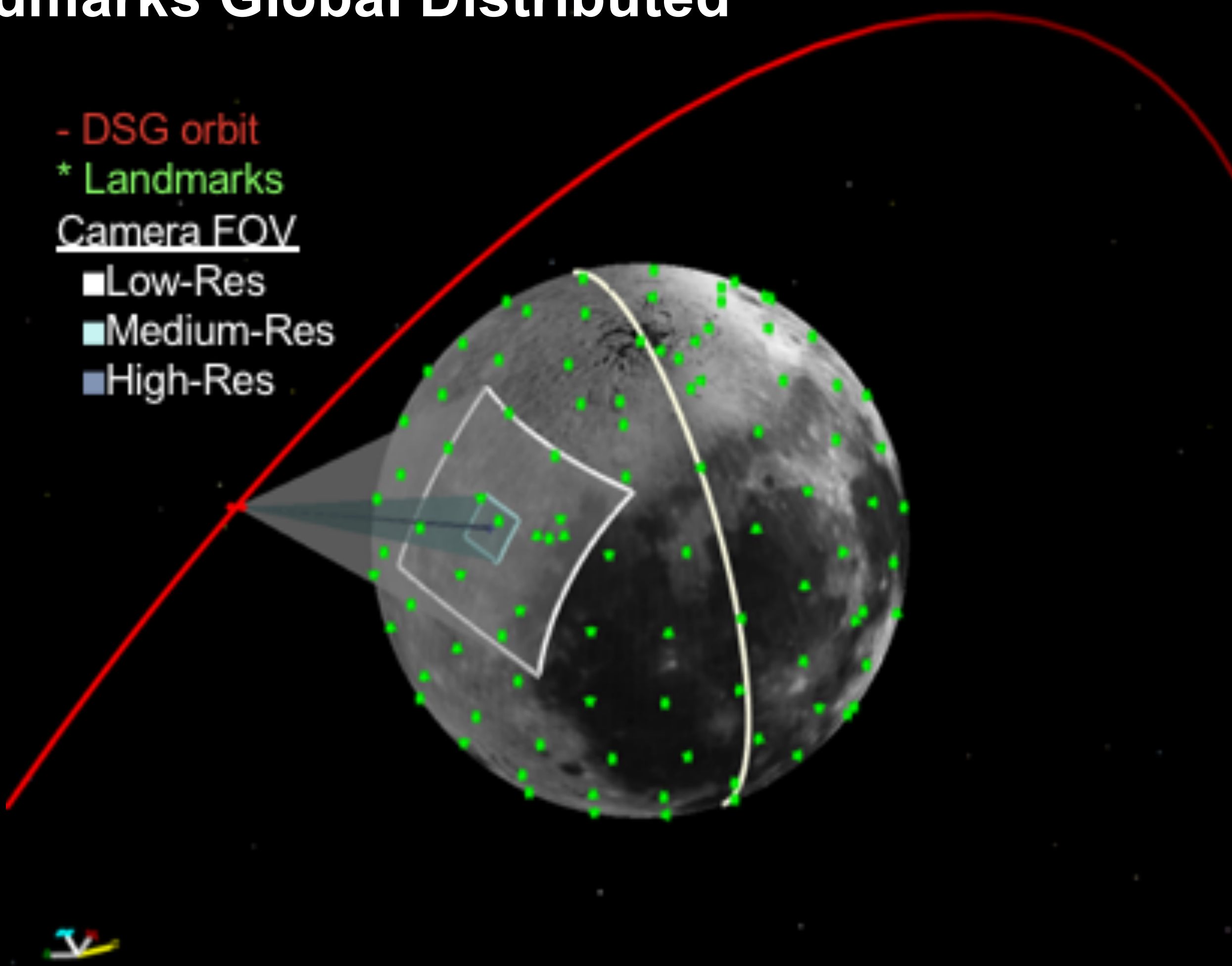


Orbit Determination Results: With Crew

DSN Tracking Only: Near-Continuous During Crewed Operations

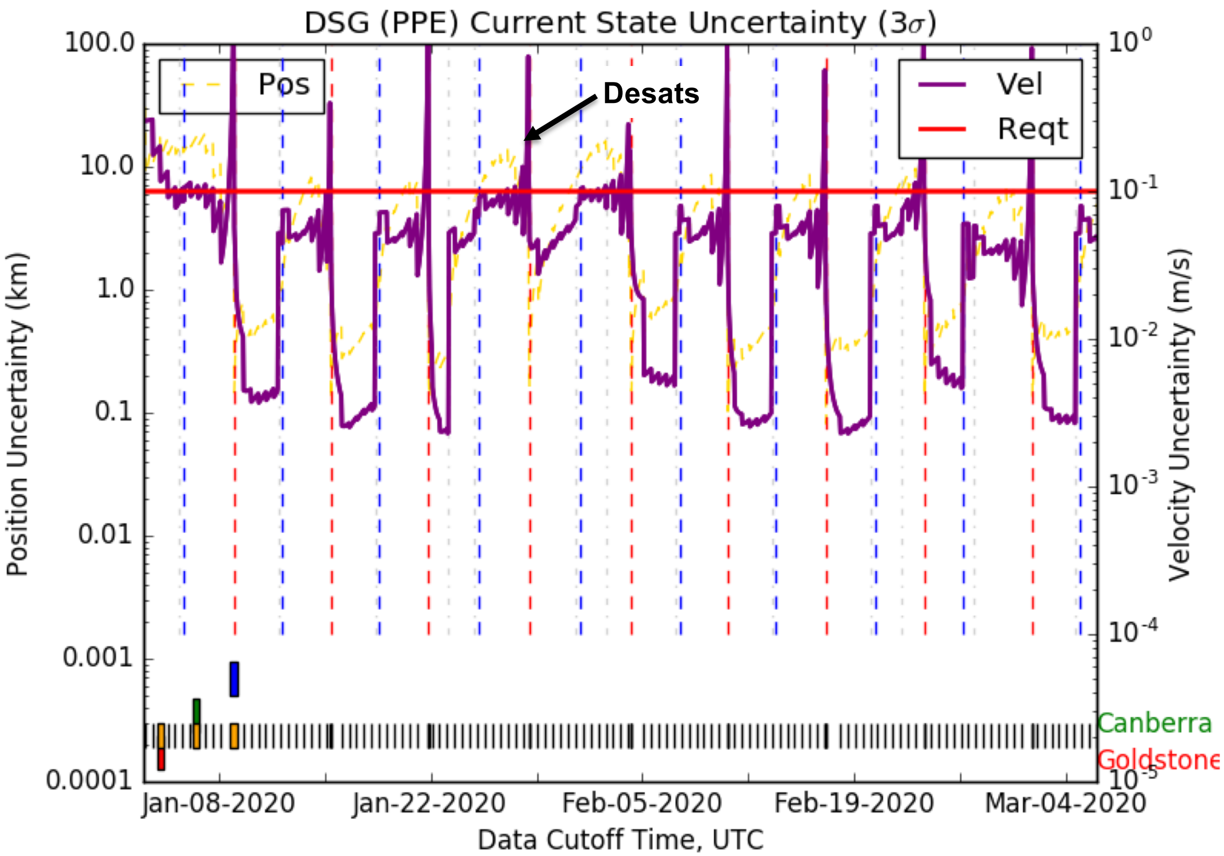


Lunar Landmarks Global Distributed



Orbit Determination Results: No Crew

On-board Optical Only: Twice per day



Conclusions

An optical only version of DPS-Navigator, relying exclusively on lunar landmark tracking from the baseline NRHO Gateway orbit, can meet existing orbit knowledge requirements needed to design and execute orbit maintenance maneuvers.

Thus, an alternative to traditional Earth-based radiometric techniques would be available to free Earth tracking stations and ground personnel for other support.

Future Uses

Enceladus is offering free (dirty) water samples for any mission that can navigate the plumes

A mission to Enceladus to search for potential life-habitats would need precision *in situ* navigation to maintain low-altitude periodic orbits around Saturn for multiple sampling flyby passes through the plumes

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Backup Material

Orbit Determination Performance Drivers

- DSN tracking schedule
- Attitude Control System (ACS) desaturation errors and frequency
- Orbit Maintenance Maneuver (OMM) errors and frequency
- Non-gravitational errors from crew activity (PSA and waste water venting)
- Solar pressure modeling uncertainties

Orbit Determination Approach

Perform linear covariance orbit determination study

- Assume NRHO 9:2 resonant orbit
- Include errors for:
  - ACS wheel desaturations
  - OMMs
  - Stochastic non-gravs due to crew activities
  - Solar radiation pressure assuming a nominal near-tail-to-sun solar pressure equilibrium attitude

Evaluate performance with various amounts of DSN tracking.

- Continuous (best case)
- Three, 6-hour tracks per week (typical)

Orbit Determination Assumptions (1/2)

Inputs

- Uncrewed mass: 7000 kg (PPE Only)
- Crewed mass: 42000 kg (PPE+SmallStack+Orion)
- Gravity:
  - Point mass: Earth, Sun & Jupiter
  - Lunar oblateness (GRAIL, 50x50)
- S-Band DSN radiometric tracking uncertainties:
  - Doppler: 1.0 mm/s (1σ), Every 60 seconds
  - Range: 1 m (1σ) , Every 5 minutes

Orbit Determination Analysis Assumptions (2/2)

Inputs

- ACS desaturations (uncrewed: once per orbit at ~20° before apolune, crewed: once per 140 min)
  - Uncertainty: 1 cm/s all axes, (1σ)
- OMM near apolune
  - Uncertainty: 2 cm/s all axes, (1σ)
- Stochastic non-grav accelerations from crew activities (a.k.a FLAK)
  - Pressure Swing Adsorption: 7.7×10^{-10} km/s^2, (1σ), τ = 623.9 seconds
  - Waste water venting: 1.0×10^{-10} km/s^2, (1σ), τ = 3 hours
- SRP Model: solar panels: 200m^2 x 2, PPE bus: 5m diameter
  - Uncertainty: 10% (1σ)